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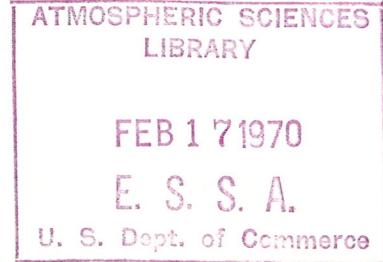
# Compilation of Reaction Rate Constants Measured in the ESSA Flowing Afterglow System to August, 1969

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BOULDER, COLORADO  
September 1969



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## ESSA TECHNICAL REPORT ERL 135-AL 3

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COMPILED OF REACTION RATE CONSTANTS MEASURED IN THE ESSA  
FLOWING AFTERGLOW SYSTEM TO AUGUST, 1969

F. C. Fehsenfeld, A. L. Schmeltekopf, D. B. Dunkin, and E. E. Ferguson

The reaction rate constants measured to August, 1969 in the ESSA flowing afterglow system have been compiled and tabulated in this report. The references to original publications are included along with references to several published reviews on specialized aspects of ion-molecule reactions. Because of the large number of measured rate constants (several hundred) this report should be useful as a reference source and "finding list".

#### INTRODUCTION

During the past half dozen years the flowing afterglow technique for ion-neutral reaction rate constant measurements has been developed and utilized in the Atmospheric Collision Processes Section of the Aeronomy Laboratory of ESSA. In the course of these studies a large number of rate constants have been determined. We have recently found it necessary for our own purposes to collect these reaction rate constants in one place. This technical report is a comprehensive tabulation of the experimental data obtained to August, 1969. The references to the published papers are given and this report may be useful to others as well as ourselves in serving as a "finding list". The compilation is divided into three sections: Positive Ion-Molecule Reactions, Negative Ion-Molecule Reactions, and Neutral Reactions. Each section is subdivided into categories depicting individual reaction types. Each category lists experimentally determined reaction channels, branching ratios, and rate constants. The temperature at which the measurement was taken and the references in which detailed information concerning the measurement is given, have also been included. The individual reactions are listed principally in order of increasing mass of the primary ion. Branching ratios are given explicitly when so determined. Rate constants refer to the loss of the primary ion or neutral particle. The most recently published value of the rate constant is listed. (-9) denotes  $10^{-9}$ . The reaction temperature is that listed last and is the kinetic gas temperature unless otherwise indicated. The references are divided into review papers and individual publications. The compilation was largely carried out by D. K. Bohme who was a member of the group as a Postdoctoral Research Associate from October 1967 to October 1969. The other members of the Atmospheric Collision Processes Laboratory are: D. L. Albritton, D. B. Dunkin, F. C. Fehsenfeld, E. E. Ferguson, W. J. Harrop, W. R. Saxton, A. L. Schmeltekopf, and Mrs. Alice Keysor, Secretary.

A. I. POSITIVE ION-MOLECULE REACTIONS:

General Bimolecular Ion-Molecule Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
C <sup>+</sup> + O <sub>2</sub> → CO <sup>+</sup> + O	300	1.1(-9)	10
C <sup>+</sup> + CO <sub>2</sub> → CO <sup>+</sup> + CO		1.9(-9)	10
N <sup>+</sup> + H <sub>2</sub> → NH <sup>+</sup> + H		5.6(-10)	13
N <sup>+</sup> + CO → CO <sup>+</sup> + N		5 (-10)	9
N <sup>+</sup> + NO → NO <sup>+</sup> + N		8(+1, -4) (-10)	8
N <sup>+</sup> + O <sub>2</sub> → O <sub>2</sub> <sup>+</sup> + N → NO <sup>+</sup> + O	{	6 (-10) <sup>a</sup>	2, 8, 19
N <sup>+</sup> + CO <sub>2</sub> → CO <sub>2</sub> <sup>+</sup> + N		1.3(-9)	9
NH <sup>+</sup> + H <sub>2</sub> → NH <sub>2</sub> <sup>+</sup> + H		~ 1 (-9)	13
NH <sup>+</sup> + N <sub>2</sub> → N <sub>2</sub> H <sup>+</sup> + N		~ 1 (-9)	13
NH <sub>2</sub> <sup>+</sup> + H <sub>2</sub> → NH <sub>3</sub> <sup>+</sup> + N		~ 1 (-9)	13
O <sup>+</sup> + H <sub>2</sub> → OH <sup>+</sup> + H		2.0(-9)	13
O <sup>+</sup> + N <sub>2</sub> → NO <sup>+</sup> + N		1.2(-12) <sup>b</sup>	2, 17, 18 19, 23
O <sup>+</sup> + NO → NO <sup>+</sup> + O		≤ 2.4(-11)	8
O <sup>+</sup> + O <sub>2</sub> → O <sub>2</sub> <sup>+</sup> + O		2 (-11) <sup>c</sup>	3, 19, 23
O <sup>+</sup> + CO <sub>2</sub> → O <sub>2</sub> <sup>+</sup> + CO		1.1(-9) <sup>d</sup>	7, 19

<sup>a</sup> Rate constant for loss of N<sup>+</sup> does not vary between 300 and 600°K within experimental uncertainty.

Splits into comparable channels.

<sup>b</sup> Decrease in rate constant ( $\propto T^{-1/2}$ ) between kinetic temperatures 80 and 600°K. Increase in rate constant by a factor of 40 with increased vibrational temperature of N<sub>2</sub>.

<sup>c</sup> Slight decrease in rate constant between 80 and 600°K.

<sup>d</sup> Slight decrease in rate constant between 300 and 600°K (almost within experimental uncertainty and data scatter). Violates Wigner spin-conservation rule.

## Positive Ion-Molecule Reactions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{OH}^+ + \text{H}_2 \rightarrow \text{H}_2\text{O}^+ + \text{H}$	300	$\sim 1.5(-9)$	13
$\text{OH}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{OH}$		$\sim 2 (-10)$	13
$\text{NH}_3^+ + \text{NH}_3 \rightleftharpoons \text{NH}_4^+ + \text{NH}_2$		$1.6(-9)$	27
$\text{H}_2\text{O}^+ + \text{H}_2 \rightarrow \text{H}_3\text{O}^+ + \text{H}$		$\sim 1.4(-9)$	13
$\text{H}_2\text{O}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{H}_2\text{O}$		$\sim 2 (-10)$	13
$\text{CO}^+ + \text{H}_2 \rightarrow \text{COH}^+ + \text{H}$		$2.0(-9)$	13
$\text{CO}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{CO}$		$2.0(-10)$	10
$\text{CO}^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + \text{CO}$		$1.1(-9)$	10
$\text{N}_2^+ + \text{H}_2 \rightarrow \text{N}_2\text{H}^+ + \text{H}$		$1.7(-9)$	13
$\text{N}_2^+ + \text{N} \rightarrow \text{N}_2 + \text{N}^+$		$< 1.0(-11)$	4
$\text{N}_2^+ + \text{O} \rightarrow \text{NO}^+ + \text{N}$		$2.5(\pm 1)(-10)$	4
$\text{N}_2^+ + \text{O} \rightarrow \text{N}_2 + \text{O}^+$		$< 1.0(-11)$	4
$\text{N}_2^+ + \text{CO} \rightarrow \text{CO}^+ + \text{N}_2$		$7 (-11)^e$	9
$\text{N}_2^+ + \text{NO} \rightarrow \text{NO}^+ + \text{N}_2$		$5(+1, -3) (-10)$	8
$\text{N}_2^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{N}_2$		$4.7(-11)^f$	2, 8, 19
$\text{N}_2^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + \text{N}_2$		$9 (-10)$	9
$\text{O}_2^+ + \text{H}_2 \rightarrow \text{products}$		$< 1 (-11)$	13
$\text{O}_2^+ + \text{N} \rightarrow \text{NO}^+ + \text{O}$		$1.8(+0.2, -0.9) (-10)$	8
$\text{O}_2^+ + \text{NH}_3 \rightarrow \text{NH}_3^+ + \text{O}_2$		$2.6(-9)$	27
$\text{O}_2^+ + \text{N}_2 \rightarrow \text{NO}^+ + \text{NO}$		$< 1 (-15)^g$	5

e Rate constant similar for isotopic  $\text{N}_2$ :  $^{15}\text{N}^{15}\text{N}$ ,  $^{15}\text{N}^{14}\text{N}$ .

f Slight decrease in rate constant between 80 and 520°K.

g Not observed at 300 and 600°K.

## Positive Ion-Molecule Reactions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
O <sub>2</sub> <sup>+</sup> + NO → NO <sup>+</sup> + O <sub>2</sub>	300	8(+2, -5) (-10)	8
O <sub>2</sub> <sup>+</sup> + CH <sub>4</sub> → CH <sub>3</sub> O <sub>2</sub> <sup>+</sup> + H		7.8(-12)	32
O <sub>2</sub> <sup>+</sup> + C <sub>2</sub> H <sub>4</sub> → C <sub>2</sub> H <sub>4</sub> <sup>+</sup> + O <sub>2</sub>		1.9(-9)	32
O <sub>2</sub> <sup>+</sup> + C <sub>2</sub> H <sub>6</sub> → products		1.6(-9) <sup>h</sup>	32
O <sub>2</sub> <sup>+</sup> + C <sub>3</sub> H <sub>8</sub> → products		1.8(-9)	32
O <sub>2</sub> <sup>+</sup> + C <sub>4</sub> H <sub>10</sub> → products		2.4(-9)	32
CO <sub>2</sub> <sup>+</sup> + H <sub>2</sub> → CO <sub>2</sub> H <sup>+</sup> + H		1.4(-9)	13
N <sub>2</sub> O <sup>+</sup> + H <sub>2</sub> → N <sub>2</sub> OH <sup>+</sup> + H		4 (-10)	13
NO <sub>2</sub> <sup>+</sup> + NO → NO <sup>+</sup> + NO <sub>2</sub>		2.9(-10)	34

<sup>h</sup> C<sub>2</sub>H<sub>5</sub><sup>+</sup> was observed to be the dominant production (91.5 percent).

A. II. POSITIVE ION-MOLECULE REACTIONS:

Bimolecular Ion-Molecule Reactions of Rare Gas Atomic,  
Molecular, and Hydride Ions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{He}^+ + \text{Ne} \rightarrow \text{He} + \text{Ne}^+$	300	< 1 (-13)	6
$\text{He}^+ + \text{Ar} \rightarrow \text{He} + \text{Ar}^+$		< 1 (-13)	6
$\text{He}^+ + \text{H}_2 \rightarrow \text{products}$		< 1 (-13)	6
$\text{He}^+ + \text{N}_2 \xrightarrow{0.7} \text{N}^+ + \text{N} + \text{He}$	{}	1.2(-9) <sup>a</sup>	1, 6, 18, 19
$\xrightarrow{0.3} \text{N}_2^+ + \text{He}$			
$\text{He}^+ + \text{O}_2 \rightarrow \text{O}^+ + \text{O} + \text{He}$		1.5(+0.2, -0.7)(-9)	1, 6
$\text{He}^+ + \text{CO} \rightarrow \text{C}^+ + \text{O} + \text{He}$		1.7(+0.2, -0.8)(-9)	6
$\text{He}^+ + \text{NO} \rightarrow \text{N}^+ + \text{O} + \text{He}$		1.5(+0.2, -0.8)(-9)	6
$\text{He}^+ + \text{CO}_2 \xrightarrow{0.80} \text{CO}^+ + \text{O} + \text{He}$	{}	1.1 ± 0.2(-9)	6
$\xrightarrow{0.15} \text{O}^+ + \text{CO} + \text{He}$			
$\xrightarrow{0.05} \text{CO}_2^+ + \text{He}$			
$\text{HeH}_2^+ + \text{H}_2 \rightarrow \text{products}$	200	≥ 3.5(-11)	35
$\text{HeH}_2^+ + \text{H}_2 \rightarrow \text{products}$		≥ 2.4(-11)	35
$\text{He}_2^+ + \text{Ne} \rightarrow \text{Ne}^+ + 2\text{He}$		6.0(-10)	33
$\text{He}_2^+ + \text{Ar} \rightarrow \text{Ar}^+ + 2\text{He}$		2.0(-10)	33
$\text{He}_2^+ + \text{Kr} \rightarrow \text{Kr}^+ + 2\text{He}$		1.85(-11)	33
$\text{He}_2^+ + \text{H}_2 \rightarrow \text{products}$		5.3(-10)	35
$\text{He}_2^+ + \text{N}_2 \rightarrow \text{N}_2^+ + 2\text{He}$		1.3(-9)	33

<sup>a</sup> Loss of  $\text{He}^+$  is independent of  $T_{\text{kin}}$  (300 - 600°K). Mechanism is a resonant charge-transfer into  $v = 3, 4$  of  $\text{N}_2^+(C_2^{\Sigma_u^+})$ , followed by spin-forbidden predissociation in  $v = 4$  yielding  $\text{N}^+$  and radiation yielding  $\text{N}_2^+(X_2^{\Pi_g^+})$ . Branching ratio increases by a factor of about 2 with  $T_{\text{vib}}$  (300 - 6000°K) of  $\text{N}_2$ . No change in specific rate for loss of  $\text{He}^+$  with  $T_{\text{vib}}$  (300 - 6000°K) of  $\text{N}_2$  within experimental error.

## Bimolecular Ion-Molecule Reactions of Rare Gas Atomic, Molecular, and Hydride Ions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{He}_2^+ + \text{CO} \rightarrow \text{CO}^+ + 2\text{He}$	200	1.4(-9)	33
$\text{He}_2^+ + \text{O}_2 \rightarrow \text{O}_2^+ + 2\text{He}$			
$\rightarrow \text{O}^+ + \text{O} + 2\text{He}$		1.05(-9)	33
$\text{He}_2^+ + \text{NO} \rightarrow \text{NO}^+ + 2\text{He}$		1.3(-9)	33
$\text{He}_2^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + 2\text{He}$			
$\rightarrow \text{O}^+ + \text{CO} + 2\text{He}$		1.8(-9)	33
$\rightarrow \text{CO}^+ + \text{O} + 2\text{He}$			
$\text{He}_2\text{H}^+ + \text{H}_2 \rightarrow \text{products}$		3.0(-10)	35
$\text{NeH}^+ + \text{H}_2 \rightarrow \text{products}$		2.0(-11)	35
$\text{NeH}_2^+ + \text{H}_2 \rightarrow \text{products}$		≤ 4.0(-13)	35
$\text{Ne}_2^+ + \text{Ar} \rightarrow \text{Ar}^+ + 2\text{Ne}$		≤ 5 (-14)	33
$\text{Ne}_2^+ + \text{Kr} \rightarrow \text{Kr}^+ + 2\text{Ne}$		≤ 5 (-13)	33
$\text{Ne}_2^+ + \text{H}_2 \rightarrow \text{products}$		1.1(-10)	35
$\text{Ne}_2^+ + \text{O}_2 \rightarrow \text{O}_2^+ + 2\text{Ne}$			
$\rightarrow \text{O}^+ + \text{O} + 2\text{Ne}$		7.1(-10)	33
$\text{Ne}_2^+ + \text{N}_2 \rightarrow \text{N}_2^+ + 2\text{Ne}$		9.1(-10)	33
$\text{Ne}_2^+ + \text{CO} \rightarrow \text{CO}^+ + 2\text{Ne}$		5.1(-10)	33
$\text{Ne}_2^+ + \text{NO} \rightarrow \text{NO}^+ + 2\text{Ne}$		7.0(-10)	33
$\text{Ne}_2^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + 2\text{Ne}$			
$\rightarrow \text{O}^+ + \text{CO} + 2\text{Ne}$		1.1(-9)	33
$\rightarrow \text{CO}^+ + \text{O} + 2\text{Ne}$			
$\text{Ne}_2\text{H}^+ + \text{H}_2 \rightarrow \text{products}$		9.6(-11)	35
$\text{Ar}^+ + \text{H}_2 \rightarrow \text{ArH}^+ + \text{H}$	280	~ 7 (-10) <sup>b</sup>	11, 13, 37
$\text{Ar}^+ + \text{D}_2 \rightarrow \text{ArD}^+ + \text{D}$		5.9(-10) <sup>b</sup>	37

<sup>b</sup> Increase in rate constant between 80 and 500°K;  $k = a + bT^x$ ,  $0.5 \leq x \leq 1.0$ .

## Bimolecular Ion-Molecule Reactions of Rare Gas Atomic, Molecular, and Hydride Ions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{Ar}^+ + \text{N}_2 \rightarrow \text{N}_2^+ + \text{Ar}$	280	4 to 10 (-12) <sup>c</sup>	37
$\text{Ar}^+ + \text{NO} \rightarrow \text{NO}^+ + \text{Ar}$	200	~ 3 (-10)	39
$\text{Ar}^+ + \text{O}_2 \rightarrow \text{O}_2^+ + \text{Ar}$	280	4. 6(-11) <sup>d</sup>	8, 11, 37
$\text{Ar}^+ + \text{CO} \rightarrow \text{CO}^+ + \text{Ar}$	300	9. 0(-11)	11
$\text{Ar}^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + \text{Ar}$		5. 8(-10)	11
$\text{ArH}^+ + \text{H}_2 \rightarrow \text{H}_3^+ + \text{Ar}$		~ 5 (-10) <sup>e</sup>	13, 37
$\text{ArD}^+ + \text{D}_2 \rightarrow \text{D}_3^+ + \text{Ar}$		~ 4 (-10) <sup>e</sup>	37
$\text{ArH}_2^+ + \text{H}_2 \rightarrow \text{products}$	200	≤ 1. 0(-14)	35
$\text{Ar}_2^+ + \text{Kr} \rightarrow \text{Kr}^+ + 2\text{Ar}$		7. 5(-10)	33
$\text{Ar}_2^+ + \text{CO} \rightarrow \text{ArCO}^+ + \text{Ar}$ $\rightarrow \text{CO}^+ + 2\text{Ar}$		8. 5(-10)	33
$\text{Ar}_2^+ + \text{O}_2 \rightarrow \text{O}_2^+ + 2\text{Ar}$		1. 2(-10)	33
$\text{Ar}_2^+ + \text{NO} \rightarrow \text{NO}^+ + 2\text{Ar}$		2. 4(-10)	33
$\text{Ar}_2^+ + \text{CO}_2 \rightarrow \text{CO}_2^+ + 2\text{Ar}$		1. 1(-9)	33
$\text{Ar}_2^+ + \text{H}_2 \rightarrow \text{products}$		4. 9(-10)	35
$\text{Ar}_2\text{H}^+ + \text{H}_2 \rightarrow \text{products}$		3. 0(-11)	35

<sup>c</sup> Dependent on Ar number density.

<sup>d</sup> Decrease in rate constant between 80 and 500°K:  $k = 7.8 \times 10^{-10} T^{-0.5}$ .

<sup>e</sup> Rate constant does not vary between 80 and 500°K within experimental uncertainty.

A. III. POSITIVE ION-MOLECULE REACTIONS:

Bimolecular Meteor Ion-Molecule Reactions

Reaction	Temp. (°K)	Rate Constant <sup>a</sup> (cm <sup>3</sup> /molecule sec)	Reference
$\text{Na}^+ + \text{O}_3 \rightarrow \text{NaO}^+ + \text{O}_2$	300	< 1.0(-11)	21
$\text{Mg}^+ + \text{O}_3 \rightarrow \text{MgO}^+ + \text{O}_2$		2.3(-10)	21
$\text{Si}^+ + \text{O}_2 \rightarrow \text{SiO}^+ + \text{O}$		< 1 (-11)	26
$\text{K}^+ + \text{O}_3 \rightarrow \text{KO}^+ + \text{O}_2$		< 1.0(-11)	21
$\text{Ca}^+ + \text{O}_3 \rightarrow \text{CaO}^+ + \text{O}_2$		1.6(-10)	21
$\text{Fe}^+ + \text{O}_3 \rightarrow \text{FeO}^+ + \text{O}_2$		1.5(-10)	21
$\text{MgO}^+ + \text{O} \rightarrow \text{Mg}^+ + \text{O}_2$		~ 1.0(-10)	21
$\text{SiO}^+ + \text{N} \xrightleftharpoons[0.5]{\text{N}} \text{Si}^+ + \text{NO}$	{}	~ 3 (-10)	26
$\xrightleftharpoons[0.5]{\text{N}} \text{NO}^+ + \text{Si}$			
$\text{SiO}^+ + \text{O} \rightarrow \text{Si}^+ + \text{O}_2$		~ 2.0(-10)	26

<sup>a</sup> Rate constants are probably reliable to within a factor of 2. Reactions with the alkaline earth ions  $\text{Ca}^+$ ,  $\text{Mg}^+$ ,  $\text{Fe}^+$  are obviously exothermic, so that the bond energies  $D_o(\text{M}^+ - \text{O}) > D_o(\text{O}_2 - \text{O}) = 1 \text{ eV}$ . The possibility exists that the reactions with the alkali metal ions  $\text{Na}^+$  and  $\text{K}^+$  are endothermic, i.e., that the bond energies  $D_o(\text{Na}^+ - \text{O})$  and  $D_o(\text{K}^+ - \text{O}) < D_o(\text{O}_2 - \text{O}) = 1 \text{ eV}$ . In the course of these studies the following metal ion oxides were observed:  $\text{MgO}_n^+$  ( $n = 1$  to 5),  $\text{Mg}_2\text{O}_n^+$  ( $n = 2, 3$ ),  $\text{Mg}_3\text{O}_3^+$ ,  $\text{CaO}_n^+$  ( $n = 1$  to 3),  $\text{Ca}_2\text{O}_n^+$  ( $n = 2, 3$ ),  $\text{Ca}_2\text{O}_4^+$ ,  $\text{FeO}_n^+$  ( $n = 1$  to 5),  $\text{Fe}_2\text{O}_4^+$ . The dimer  $\text{Fe}_2^+$  ion was also observed.

A. IV. POSITIVE ION-MOLECULE REACTIONS:

Switching Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{HeNe}^+ + \text{Ne} \rightarrow \text{Ne}_2^+ + \text{He}$	200	1.4(-10)	33
$\text{ArKr}^+ + \text{Kr} \rightarrow \text{Kr}_2^+ + \text{Ar}$		3.2(-10)	33
$\text{ArCO}^+ + \text{CO} \rightarrow \text{CO}^+ \cdot \text{CO} + \text{Ar}$		4.6(-10)	33
$\text{ArO}_2^+ + \text{O}_2 \rightarrow \text{O}_4^+ + \text{Ar}$	80	2.5(-11)	37
$\text{O}_2^+ \cdot \text{N}_2 + \text{O}_2 \rightarrow \text{O}_2^+ \cdot \text{O}_2 + \text{N}_2$	80	$\geq 5.0(-11)$	38
$\text{O}_2^+ \cdot \text{O}_2 + \text{N}_2\text{O} \rightarrow \text{O}_2^+ \cdot \text{N}_2\text{O} + \text{O}_2$	200	2.5(-10) <sup>a</sup>	38
$\text{O}_2^+ \cdot \text{O}_2 + \text{SO}_2 \rightarrow \text{O}_2^+ \cdot \text{SO}_2 + \text{O}_2$	200	8.2(-10)	38
	300	4.2(-10) <sup>b</sup>	38
$\text{O}_2^+ \cdot \text{N}_2\text{O} + \text{H}_2\text{O} \rightarrow \text{O}_2^+ \cdot \text{H}_2\text{O} + \text{N}_2\text{O}$		$> 1.0(-10)$	38
$\text{O}_2^+ \cdot \text{N}_2\text{O} + \text{SO}_2 \rightarrow \text{O}_2^+ \cdot \text{SO}_2 + \text{N}_2\text{O}$	200	5.6(-10)	38
$\text{O}_2^+ \cdot \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{O}_2^+ \cdot \text{H}_2\text{O} + \text{SO}_2$	300	$> 1.0(-10)$	38

<sup>a</sup> The equilibrium constant  $K = 1.3(3)$ ,  $\Delta F^\circ = 0.13$  eV.

<sup>b</sup> The equilibrium constant  $K = 3.2(4)$ ,  $\Delta F^\circ = 0.27$  eV.

A. V. POSITIVE ION-MOLECULE REACTIONS:

Termolecular Ion-Neutral Association Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>6</sup> /molecule <sup>2</sup> sec)	Reference
H <sub>3</sub> <sup>+</sup> + Ar + Ar → H <sub>3</sub> <sup>+</sup> · Ar + Ar	300	≈ 1.0(-31)	13
N <sup>+</sup> + N <sub>2</sub> + He → N <sup>+</sup> · N <sub>2</sub> + He	80	7.2(-29)	24
O <sup>+</sup> + N <sub>2</sub> + He → (O <sup>+</sup> · N <sub>2</sub> ) <sup>*</sup> + He		5.4(-29)	24
NH <sub>4</sub> <sup>+</sup> + NH <sub>3</sub> + O <sub>2</sub> → NH <sub>4</sub> <sup>+</sup> · NH <sub>3</sub> + O <sub>2</sub>	300	1.8(-27)	27
Na <sup>+</sup> + O <sub>2</sub> + Ar → Na <sup>+</sup> · O <sub>2</sub> + Ar		< 2.0(-31)	21
Mg <sup>+</sup> + O <sub>2</sub> + Ar → Mg <sup>+</sup> · O <sub>2</sub> + Ar		~ 2.5(-30)	21
N <sub>2</sub> <sup>+</sup> + N <sub>2</sub> + He → N <sub>2</sub> <sup>+</sup> · N <sub>2</sub> + He	80	1.2(-28)	22, 24
	280	1.9(-29)	24
NO <sup>+</sup> + H <sub>2</sub> O + He → NO <sup>+</sup> · H <sub>2</sub> O + He	300	5.5(-29)	36
NO <sup>+</sup> + H <sub>2</sub> O + N <sub>2</sub> → NO <sup>+</sup> · H <sub>2</sub> O + N <sub>2</sub>		2.2(-28)	36
NO <sup>+</sup> + H <sub>2</sub> O + Ar → NO <sup>+</sup> · H <sub>2</sub> O + Ar		1.9(-28)	36
O <sub>2</sub> <sup>+</sup> + H <sub>2</sub> + He → O <sub>2</sub> <sup>+</sup> · H <sub>2</sub> + He	80	7.4(-31)	38
O <sub>2</sub> <sup>+</sup> + H <sub>2</sub> O + He → O <sub>2</sub> <sup>+</sup> · H <sub>2</sub> O + He	300	8.5(-29)	36
O <sub>2</sub> <sup>+</sup> + H <sub>2</sub> O + N <sub>2</sub> → O <sub>2</sub> <sup>+</sup> · H <sub>2</sub> O + N <sub>2</sub>		4.5(-28)	36
O <sub>2</sub> <sup>+</sup> + H <sub>2</sub> O + Ar → O <sub>2</sub> <sup>+</sup> · H <sub>2</sub> O + Ar		3.5(-28)	36
O <sub>2</sub> <sup>+</sup> + N <sub>2</sub> + He → O <sub>2</sub> <sup>+</sup> · N <sub>2</sub> + He	80	1.9(-29)	38
O <sub>2</sub> <sup>+</sup> + O <sub>2</sub> + He → O <sub>2</sub> <sup>+</sup> · O <sub>2</sub> + He	200	3.1(-29)	22, 24
		2.4(-30)	24
O <sub>2</sub> <sup>+</sup> + CO <sub>2</sub> + He → O <sub>2</sub> <sup>+</sup> · CO <sub>2</sub> + He	200	2.3(-29)	38
O <sub>2</sub> <sup>+</sup> + N <sub>2</sub> O + He → O <sub>2</sub> <sup>+</sup> · N <sub>2</sub> O + He		5.2(-29)	38
O <sub>2</sub> <sup>+</sup> + SO <sub>2</sub> + He → O <sub>2</sub> <sup>+</sup> · SO <sub>2</sub> + He		~ 6 (-28)	38
K <sup>+</sup> + O <sub>2</sub> + Ar → K <sup>+</sup> · O <sub>2</sub> + Ar	300	< 2.0(-31)	21
Ca <sup>+</sup> + O <sub>2</sub> + Ar → Ca <sup>+</sup> · O <sub>2</sub> + Ar		~ 6.6(-30)	21

## Termolecular Ion-Neutral Association Reactions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>6</sup> /molecule <sup>2</sup> sec)	Reference
$\text{Ar}^+ + \text{Ar} + \text{He} \rightarrow \text{Ar}^+\cdot\text{Ar} + \text{He}$	80	$1.6(-30)$	24
	290	$\sim 1.3(-31)$	24
$\text{Fe}^+ + \text{O}_2 + \text{Ar} \rightarrow \text{Fe}^+\cdot\text{O}_2 + \text{Ar}$		$\sim 1.0(-30)$	21
$\text{O}_2^+\cdot\text{N}_2 + \text{N}_2 + \text{He} \rightarrow \text{O}_2^+\cdot 2\text{N}_2 + \text{He}$	80	$\sim 1.0(-29)$	38
$\text{O}_2^+\cdot\text{O}_2 + \text{N}_2 + \text{He} \rightarrow \text{O}_2^+\cdot\text{O}_2\cdot\text{N}_2 + \text{He}$		$\sim 1.0(-29)$	38
$\text{O}_2^+\cdot\text{O}_2 + \text{O}_2 + \text{He} \rightarrow \text{O}_2^+\cdot 2\text{O}_2 + \text{He}$		$\sim 5.0(-30)$	38
$\text{Ar}_2^+ + \text{Ar} + \text{He} \rightarrow \text{Ar}_3^+ + \text{He}$	80	$\sim 5.5(-31)$	29
$\text{Xe}^+ + \text{H}_2\text{O} + \text{He} \rightarrow \text{Xe}^+\cdot\text{H}_2\text{O} + \text{He}$	300	$1.5(-29)$	36

B. I. NEGATIVE ION-MOLECULE REACTIONS:

Charge-Transfer Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
H <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + H	300	2.9(-9)	C
NH <sub>2</sub> <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + NH <sub>2</sub>		1.0(-9)	C
O <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + O		1.2(-9)	C
O <sup>-</sup> + O <sub>3</sub> → O <sub>3</sub> <sup>-</sup> + O		5.3(-10)	15, C
OH <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + OH		1.0(-9)	C
F <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + F		< 2.5(-11)	C
NO <sup>-</sup> + O <sub>2</sub> → O <sub>2</sub> <sup>-</sup> + NO	9	(-10)	12
O <sub>2</sub> <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + O <sub>2</sub>	8	(-10)	20, C
O <sub>2</sub> <sup>-</sup> + O <sub>3</sub> → O <sub>3</sub> <sup>-</sup> + O <sub>2</sub>		4.0(-10)	15, C
O <sub>2</sub> <sup>-</sup> + SO <sub>2</sub> → SO <sub>2</sub> <sup>-</sup> + O <sub>2</sub>		5.4(-10)	D
Cl <sup>-</sup> + NO <sub>2</sub> → NO <sub>2</sub> <sup>-</sup> + Cl		< 6 (-12)	20, C

B. II. NEGATIVE ION-MOLECULE REACTIONS:

Bimolecular Ion-Molecule Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
O <sup>-</sup> + NH <sub>3</sub> → OH <sup>-</sup> + NH <sub>2</sub>	300	1.2(-9)	27
N <sub>2</sub> O <sup>-</sup> + O <sub>2</sub> → O <sub>3</sub> <sup>-</sup> + N <sub>2</sub>	80	fast	B
NO <sub>2</sub> <sup>-</sup> + N → products	300	< 1 (-11)	39
NO <sub>2</sub> <sup>-</sup> + O → products		< 1 (-11)	39
NO <sub>2</sub> <sup>-</sup> + NO <sub>2</sub> → NO <sub>3</sub> <sup>-</sup> + NO		~ 4 (-12)	30
NO <sub>2</sub> <sup>-</sup> + O <sub>3</sub> → NO <sub>3</sub> <sup>-</sup> + O <sub>2</sub>		1.8(-11)	20
O <sub>3</sub> <sup>-</sup> + CO → products		< 1.0(-12)	B, 39
O <sub>3</sub> <sup>-</sup> + N <sub>2</sub> → products		< 1 (-15)	B
O <sub>3</sub> <sup>-</sup> + NO → NO <sub>3</sub> <sup>-</sup> + O		1.0(-11)	15
O <sub>3</sub> <sup>-</sup> + SiO → SiO <sub>3</sub> <sup>-</sup> + O		fast	B
O <sub>3</sub> <sup>-</sup> + CO <sub>2</sub> → CO <sub>3</sub> <sup>-</sup> + O <sub>2</sub>		4.0(-10) <sup>a</sup>	15, 38
O <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> → products		1.9(-10)	B
O <sub>3</sub> <sup>-</sup> + SO <sub>2</sub> → SO <sub>4</sub> <sup>-</sup> + O → SO <sub>3</sub> <sup>-</sup> + O <sub>2</sub>	{}	5.1(-10)	B
CO <sub>3</sub> <sup>-</sup> + O → O <sub>2</sub> <sup>-</sup> + CO <sub>2</sub>		8.0(-11)	15
CO <sub>3</sub> <sup>-</sup> + NO → NO <sub>2</sub> <sup>-</sup> + CO <sub>2</sub>		9.0(-12) <sup>b</sup>	15, 38
CO <sub>3</sub> <sup>-</sup> + N <sub>2</sub> → products		< 1.0(-12)	39
CO <sub>3</sub> <sup>-</sup> + NO <sub>2</sub> → NO <sub>3</sub> <sup>-</sup> + CO <sub>2</sub>		8.0(-11)	B
NO <sub>3</sub> <sup>-</sup> + O → products		< 1 (-11)	30
NO <sub>3</sub> <sup>-</sup> + N → products		< 1 (-11)	30

<sup>a</sup> The equilibrium constant K ≥ 1.4(5), ΔF<sup>°</sup> ≥ 0.31 eV.

<sup>b</sup> The equilibrium constant K = 11, ΔF<sup>°</sup> = 0.06 eV.

Bimolecular Ion-Molecule Reactions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
$\text{NO}_3^- + \text{CO} \rightarrow \text{products}$	300	$< 1 (-12)$	39
$\text{NO}_3^- + \text{NO} \rightarrow \text{NO}_2^- + \text{NO}_2$		$< 1 (-12)$	30
$\begin{array}{l} \text{O}_4^- + \text{O} \rightarrow \text{O}_3^- + \text{O}_2 \\ \quad \rightarrow \text{O}^- + 2\text{O}_2 \end{array} \quad \left. \right\}$		4 (-10)	30
$\begin{array}{l} \text{CO}_4^- + \text{O} \rightarrow \text{CO}_3^- + \text{O}_2 \\ \quad \rightarrow \text{O}_3^- + \text{CO}_2 \end{array} \quad \left. \right\}$		1.5(-10)	30

B. III. NEGATIVE ION-MOLECULE REACTIONS:

Associative Detachment Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
H <sup>-</sup> + H → H <sub>2</sub> + e	300	1.3(-9)	14
H <sup>-</sup> + O <sub>2</sub> → HO <sub>2</sub> + e		1.8(-9)	39
O <sup>-</sup> + H <sub>2</sub> → H <sub>2</sub> O + e		~ 1.5(-9)	12, B, C, 31
O <sup>-</sup> + N → NO + e		2.0(-10)	12, 15, B
O <sup>-</sup> + O → O <sub>2</sub> + e		1.4(-10)	12, 15, B, C
O <sup>-</sup> + N <sub>2</sub> → N <sub>2</sub> O + e		< 1.0(-14)	12, 31
O <sup>-</sup> + CO → CO <sub>2</sub> + e		4.4(-10)	12, B, C
O <sup>-</sup> + NO → NO <sub>2</sub> + e		1.6(-10)	12, B, C
O <sup>-</sup> + O <sub>2</sub> → O <sub>3</sub> + e		< 1 (-12)	12
O <sup>-</sup> + O <sub>2</sub> ( <sup>1</sup> Δ <sub>g</sub> ) → O <sub>3</sub> ( <sup>1</sup> A <sub>1</sub> ) + e		~ 3.0(-10)	25
O <sup>-</sup> + CO <sub>2</sub> → CO <sub>3</sub> + e		< 1 (-13)	24
O <sup>-</sup> + SO <sub>2</sub> → SO <sub>3</sub> + e		6.9(-10) <sup>a</sup>	39
OH <sup>-</sup> + H → H <sub>2</sub> O + e		1.0(-9)	B
OH <sup>-</sup> + N → HNO + e		< 1 (-11)	12, 31
OH <sup>-</sup> + O → HO <sub>2</sub> + e		2.0(-10)	12, B
CN <sup>-</sup> + H → HCN + e		8 (-10)	B, C
O <sub>2</sub> <sup>-</sup> + N → NO <sub>2</sub> + e		3.0(-10)	12, 15, B
O <sub>2</sub> <sup>-</sup> + O → O <sub>3</sub> + e		3.0(-10)	12, 15, B
O <sub>2</sub> <sup>-</sup> + O <sub>2</sub> ( <sup>1</sup> Δ <sub>g</sub> ) → 2O <sub>2</sub> ( <sup>3</sup> Σ <sub>g</sub> ) + e		~ 2 (-10)	25
S <sup>-</sup> + H <sub>2</sub> → H <sub>2</sub> S + e		< 1.0(-15)	31
S <sup>-</sup> + CO → COS + e		3.1(-10)	39

<sup>a</sup> There is the possibility of some charge-transfer.

Associative Detachment Reactions (continued)

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
S <sup>-</sup> + O <sub>2</sub> → SO <sub>2</sub> + e	300	5.5(-11)	31
Cl <sup>-</sup> + H → HCl + e		9 (-10)	12, B, C
Cl <sup>-</sup> + N → ClN + e	< 1	(-11)	12
Cl <sup>-</sup> + O → ClO + e	< 1	(-11)	12

## B. IV. NEGATIVE ION-MOLECULE REACTIONS:

## Switching Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>3</sup> /molecule sec)	Reference
O <sub>2</sub> <sup>-</sup> .H <sub>2</sub> O + NO → O <sub>2</sub> <sup>-</sup> .NO + H <sub>2</sub> O	300	3.1(-10)	38
O <sub>2</sub> <sup>-</sup> .H <sub>2</sub> O + CO <sub>2</sub> → O <sub>2</sub> <sup>-</sup> .CO <sub>2</sub> + H <sub>2</sub> O		5.8(-10)	38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + CO → O <sub>2</sub> <sup>-</sup> .CO + O <sub>2</sub>		< 2.0(-11)	38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + N <sub>2</sub> → O <sub>2</sub> <sup>-</sup> .N <sub>2</sub> + O <sub>2</sub>		< 1.0(-11)	38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + NO → O <sub>2</sub> <sup>-</sup> .NO + O <sub>2</sub>		2.5(-10)	30, 38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + H <sub>2</sub> O → O <sub>2</sub> <sup>-</sup> .H <sub>2</sub> O + O <sub>2</sub>		> 1.0(-10)	38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + CO <sub>2</sub> → O <sub>2</sub> <sup>-</sup> .CO <sub>2</sub> + O <sub>2</sub>		4.3(-10)	30, 38
O <sub>2</sub> <sup>-</sup> .O <sub>2</sub> + N <sub>2</sub> O → O <sub>2</sub> <sup>-</sup> .N <sub>2</sub> O + O <sub>2</sub>		< 1.0(-12)	38
O <sub>2</sub> <sup>-</sup> .CO <sub>2</sub> + NO → O <sub>2</sub> <sup>-</sup> .NO + CO <sub>2</sub>		4.8(-11)	30, 38

B. V. NEGATIVE ION-MOLECULE REACTIONS:

Termolecular Ion-Neutral Association Reactions

Reaction	Temp. (°K)	Rate Constant (cm <sup>6</sup> /molecule <sup>2</sup> sec)	Reference
$O^- + N_2 + He \rightarrow O^-.N_2 + He$	80	$\sim 1.0(-30)$	D
	200	$\sim 4.0(-32)$	38
$O^- + CO_2 + He \rightarrow O^-.CO_2 + He$	280	$1.5(-28)$	24
	200	$2.6(-28)$	38
$O_2^- + N_2 + He \rightarrow O_2^-.N_2 + He$	200	$\sim 4.0(-32)$	38
$O_2^- + O_2 + He \rightarrow O_2^-.O_2 + He$	200	$3.4(-31)$	38
$O_2^- + CO_2 + He \rightarrow O_2^-.CO_2 + He$	200	$4.7(-29)$	38
$O_3^- + N_2 + N_2 \rightarrow \text{products}$	300	$< 1.5(-31)$	D

B. VI. NEGATIVE ION-MOLECULE REACTIONS:

Bimolecular Ion-Organic Molecule Reactions

Reaction	Branching Ratio	Rate Constant at 300°K (cm <sup>3</sup> /molecule sec)	Reference
$O^- + CH_4 \rightarrow OH^- + CH_3$		1.0(-10)	28
$O^- + C_2H_6 \rightarrow OH^- + C_2H_5$		7.0(-10)	28
$O^- + C_3H_8 \rightarrow OH^- + C_3H_7$		9.3(-10)	28
$O^- + n - C_4H_{10} \rightarrow OH^- + C_4H_9$		1.2(-9)	28
$O^- + C_2H_4 \rightarrow C_2H_4^- + e^-$		7.7(-10)	40
$O^- + C_3H_4 \rightarrow C_3H_3^- + OH$	0.90 ± 0.05	1.0(-9)	40
$\rightarrow OH^- + C_3H_3$	0.10 ± 0.05		
$O^- + C_3H_6 \rightarrow OH^- + C_3H_5$	0.95 ± 0.05	1.0(-9)	40
$\rightarrow C_3H_5^- + OH$	0.05 ± 0.05		
$O^- + iso - C_4H_8 \rightarrow OH^- + C_4H_7$	0.95 ± 0.05	1.4(-9)	40
$\rightarrow C_4H_7^- + OH$	0.05 ± 0.05		
$O^- + l - C_4H_8 \rightarrow C_4H_7^- + OH$	0.6 ± 0.1	1.4(-9)	40
$\rightarrow OH^- + C_4H_7$	0.4 ± 0.1		
$O^- + cis - 2 - C_4H_8 \rightarrow C_4H_7^- + OH$	0.6 ± 0.1	1.2(-9)	40
$\rightarrow OH^- + C_4H_7$	0.4 ± 0.1		
$O^- + trans - 2 - C_4H_8 \rightarrow C_4H_7^- + OH$	0.6 ± 0.1	1.6(-9)	40
$\rightarrow OH^- + C_4H_7$	0.4 ± 0.1		
$OH^- + RH \rightarrow R^- + H_2O$		≤ 1 (-12) <sup>a</sup>	28
$OH^- + C_2H_4 \rightarrow C_2H_3^- + H_2O$		≤ 1 (-12)	40

<sup>a</sup> RH = CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>8</sub>, C<sub>4</sub>H<sub>10</sub>

## Bimolecular Ion-Organic Molecule Reactions (continued)

Reaction	Branching Ratio	Rate Constant at 300°K (cm <sup>3</sup> /molecule sec)	Reference
$\text{OH}^- + \text{C}_3\text{H}_4 \rightarrow \text{C}_3\text{H}_3^- + \text{H}_2\text{O}$		7.5(-10)	40
$\text{OH}^- + \text{C}_3\text{H}_6 \rightarrow \text{C}_3\text{H}_5^- + \text{H}_2\text{O}$		2.6(-10)	40
$\text{OH}^- + \underline{\text{iso}} - \text{C}_4\text{H}_8 \rightarrow \text{C}_4\text{H}_7^- + \text{H}_2\text{O}$		6.3(-10)	40
$\text{OH}^- + 1 - \text{C}_4\text{H}_8 \rightarrow \text{C}_4\text{H}_7^- + \text{H}_2\text{O}$		8.8(-10)	40
$\text{OH}^- + \underline{\text{cis}} - 2 - \text{C}_4\text{H}_8 \rightarrow \text{C}_4\text{H}_7^- + \text{H}_2\text{O}$		7.2(-10)	40
$\text{OH}^- + \underline{\text{trans}} - 2 - \text{C}_4\text{H}_8 \rightarrow \text{C}_4\text{H}_7^- + \text{H}_2\text{O}$		8.7(-10)	40
$\text{C}_3\text{H}_3^- + \text{O}_2 \rightarrow \text{C}_2\text{HO}^- + \text{H}_2\text{CO}$		1.0(-12)	40
$\text{C}_3\text{H}_5^- + \text{O}_2 \rightarrow \text{O}_2^- + \text{C}_3\text{H}_5$	0.98 ± 0.01	{}	40
$\rightarrow \text{C}_2\text{H}_3\text{O}^- + \text{CH}_2\text{O}$	0.02 ± 0.01		
$\text{C}_4\text{H}_7^- + \text{O}_2 \rightarrow \text{O}_2^- + \text{C}_4\text{H}_7$	0.69 ± 0.05	{}	40
$\rightarrow \text{C}_3\text{H}_3^- + \text{CH}_4\text{O}_2$	0.14 ± 0.03		
$\rightarrow \text{O}_2\text{H}^- + \text{C}_4\text{H}_6$	0.08 ± 0.04		
$\rightarrow \text{C}_2\text{HO}^- + \text{C}_2\text{H}_6\text{O}$	0.05 ± 0.02		
$\rightarrow \text{C}_2\text{H}_3\text{O}^- + \text{C}_2\text{H}_4\text{O}$	0.04 ± 0.01		
$\text{C}_4\text{H}_7^- + \text{O}_2 \rightarrow \text{O}_2\text{H}^- + \text{C}_4\text{H}_6$	0.62 ± 0.05	{}	40
$\rightarrow \text{O}_2^- + \text{C}_4\text{H}_7$	0.34 ± 0.03		
$\rightarrow \text{C}_2\text{H}_3\text{O}^- + \text{C}_2\text{H}_4\text{O}$	0.02 ± 0.01		
$\rightarrow \text{C}_2\text{HO}^- + \text{C}_2\text{H}_6\text{O}$	0.01 ± 0.01		
$\rightarrow \text{C}_3\text{H}_3^- + \text{CH}_4\text{O}_2$	0.01 ± 0.01		

b  $\text{C}_4\text{H}_7^-$  derived from iso -  $\text{C}_4\text{H}_8$ .

c  $\text{C}_4\text{H}_7^-$  derived from 1 -  $\text{C}_4\text{H}_8$ , cis - 2 -  $\text{C}_4\text{H}_8$ , and trans - 2 -  $\text{C}_4\text{H}_8$ .

C. I. NEUTRAL REACTIONS:

Metastable Helium Reactions (Reference 41)

Reactant	Rate Constant ( $\text{cm}^3/\text{molecule sec}$ ) at $300^\circ\text{K}$ .	
	$\text{He}(^1\text{S})$	$\text{He}(^3\text{S})$
Ne	6.46(-11)	3.85(-12)
Ar	2.20(-10)	7.04(-11)
Kr	3.62(-10)	9.94(-11)
Xe	4.62(-10)	1.24(-10)
$\text{H}_2$	4.88(-11)	3.18(-11)
$\text{D}_2$	4.15(-11)	2.60(-11)
$\text{NH}_3$	1.33(-9)	8.40(-10)
$\text{N}_2$	1.67(-10)	6.96(-11)
CO	3.17(-10)	9.85(-11)
NO	4.33(-10)	2.42(-10)
$\text{O}_2$	5.80(-10)	2.10(-10)
$\text{N}_2\text{O}$	9.18(-10)	4.33(-10)
$\text{CO}_2$	1.10(-9)	5.75(-10)
$\text{CH}_4$	3.75(-10)	1.37(-10)
$\text{C}_2\text{H}_6$	5.67(-10)	2.50(-10)
$\text{C}_3\text{H}_8$	7.00(-10)	3.17(-10)
$\text{C}_4\text{H}_{10}$	9.00(-10)	4.17(-10)
$\text{SF}_6$	6.66(-10)	2.62(-10)



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